Impact of Spectroscopic and Atmospheric State Knowledge on Retrieved XCO2 and XCH4 Column Amounts from Laser Differential Absorption Spectrometer Measurements

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Abstract

In this work we extend previous studies by exploring the potential impact of spectroscopic knowledge along with atmospheric state knowledge on retrievals of carbon dioxide (XCO2) and methane (XCH4) column amounts from laser differential absorption spectrometer (LAS) measurements. This has been done for multiple CO2 absorption lines in the 1.57 and 2.05 µm regions, and for CH4 in the 1.65 µm region. One such potential source of error in performing XCO2 retrievals is modeled surface pressure. Since it has been proposed to derive surface pressure from LAS-based O2 measurements in lieu of modeled surface pressure for use in XCO2 retrievals as a means of error reduction, our past work has also attempted to characterize and quantify potential improvements in XCO2 retrieval error associated with O2-derived surface pressure for a set of CO2 and O2 absorption line combinations. All of our previous analyses have relied on a radiative-transfer-based simulation framework utilizing the Line-by-Line Radiative Transfer Model (LBLRTM), version 12.2 (release date November, 2012). LBLRTM has undergone several upgrades since version 12.2, to include updates to its line parameter database, updates to its continuum model, and bug fixes. Our current work revisits our prior assessments using the latest version of LBLRTM (version 12.8) and comparisons are provided and discussed.

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In this work we extend previous studies by exploring the potential impact of spectroscopic knowledge along with atmospheric state knowledge on retrievals of carbon dioxide (XCO_2) and methane (XCH_4) column amounts from laser differential absorption spectrometer (LAS) measurements. This has been done for multiple CO_2 absorption lines in the 1.57 and 2.05 µm regions, and for CH_4 in the 1.65 µm region. One such potential source of error in performing XCO_2 retrievals is modeled surface pressure. Since it has been proposed to derive surface pressure from LAS-based O_2 measurements in lieu of modeled surface pressure for use in XCO_2 retrievals as a means of error reduction, our past work has also attempted to characterize and quantify potential improvements in XCO_2 retrieval error associated with O_2-derived surface pressure for a set of CO_2 and O_2 absorption line combinations.

All of our previous analyses have relied on a radiative-transfer-based simulation framework utilizing the Line-by-Line Radiative Transfer Model (LBLRTM), version 12.2 (release date November, 2012). LBLRTM has undergone several upgrades since version 12.2, to include updates to its line parameter database, updates to its continuum model, and bug fixes. Our current work revisits our prior assessments using the latest version of LBLRTM (version 12.8) and comparisons are provided and discussed.

Measuring Column X

LAS estimates of column-averaged dry air mixing ratios (X) that are derived from observed differential optical depths ($\Delta\tau$) require measured or prior knowledge of atmospheric state parameters that include temperature (T), moisture and pressure along the viewing path. X can be related to $\Delta\tau$ as:

$$X = \frac{\Delta\tau + \Delta\tau_{other}}{\int_0^{p_{sfc}} \Delta\sigma(\lambda_{on}, \lambda_{off}, T, p)(1-q)\,dp}$$

where $\Delta\tau_{other}$ represents residual observed $\Delta\tau$ due to other species, $\Delta\sigma$ is differential absorption cross section for the species of interest, p_{sfc} is surface pressure, q is local specific humidity and $\lambda_{on}/\lambda_{off}$ represent the observation on/off-line wavelengths. So the accuracy of retrieved X values depends on the ability to accurately characterize p, T, and q along the observed path.

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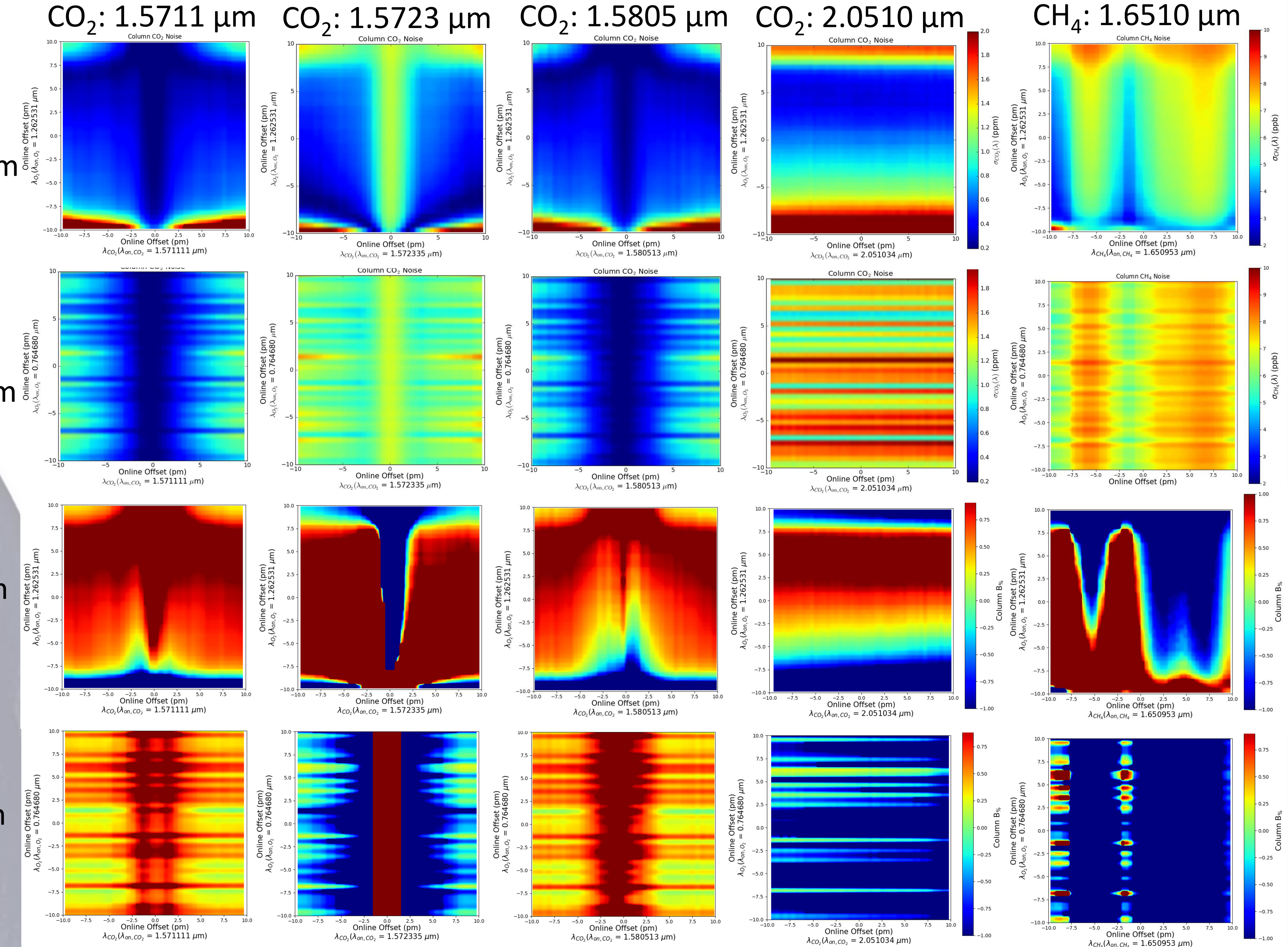
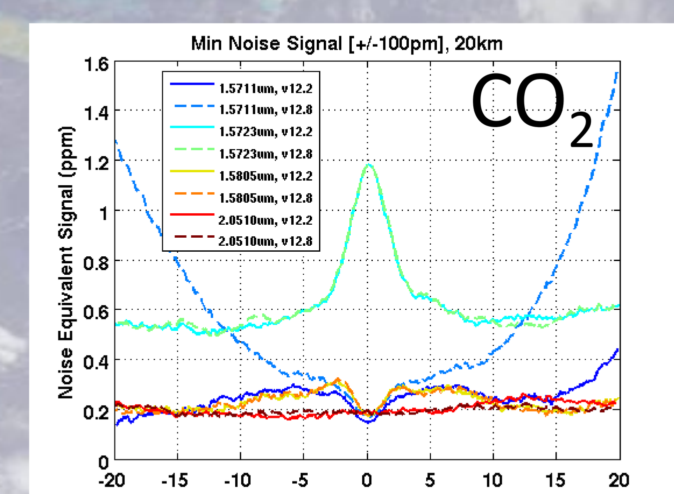
Methodology

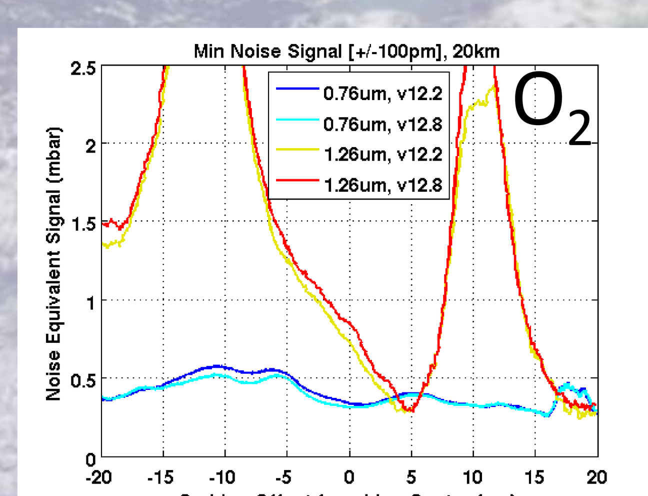
1. Model expected uncertainties or knowledge of atmospheric state as an ensemble set of collocated observed and modeled value pairs
   - Surface parameters: Pressure
   - Upper atmosphere: Vertical temperature and moisture
2. Compute simulated optical depths based on RT modeling approach
   - Expected signal due to change in column concentrations
   - Expected "noise" due to uncertainties in atmospheric state
3. Estimate signal to noise ratios for notional instruments given uncertainties in atmospheric state.
   - Relate noise equivalent signal associated with the atmospheric state to the computed signal levels.
4. Combine CO_2 (or CH_4) and O_2 retrieval mechanisms to determine impact of O_2 retrieval on CO_2 (or CH_4) column amount given uncertainties in atmospheric state.

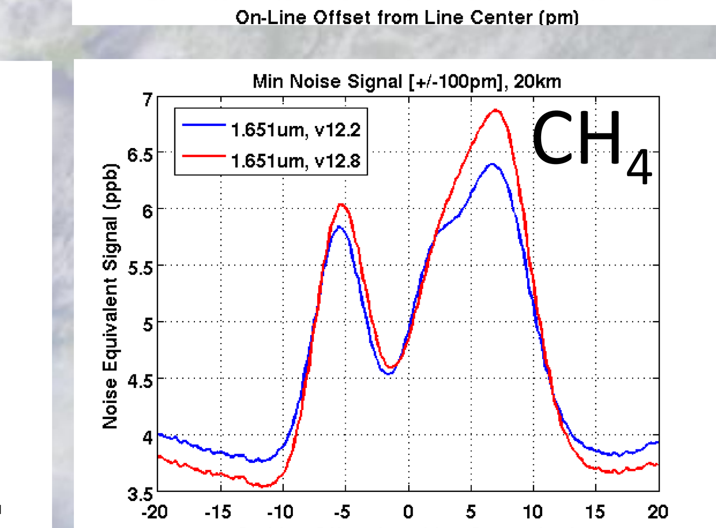
O_2-Derived P_{sfc} Analysis



Line Analysis and RTM Comparisons







Conclusions

- Uncertainties in atmospheric surface pressure and vertical temperature/moisture play a critical role in line selections for LAS measurements used in retrievals of CO_2, CH_4, and O_2 column concentrations
- Line analysis provides assessment of uncertainties in modeled T/RH/P on single line characteristics and estimates optimal on/off line parameters that minimize this retrieval error term
  - Uncertainties in vertical T and RH may introduce 0.3 to 1.5 ppm error in XCO_2, 0.3 to >2.5 ppm error in XO_2, and 3.5 to 6.5 ppb error in XCH_4 (depending on choice of on/off line pair)
  - Impact of uncertainties in pressure is tightly coupled with weighting function peak height
- RTM comparisons show that of all CO_2, CH_4, and O_2 lines analyzed, only the 1.5711 µm CO_2 line is significantly affected by updates to the LBLRTM spectroscopy. The affect is amplified in the wings of the absorption peak.
- Combined CO_2/O_2 and CH_4/O_2 analyses examine the interactions between retrieval uncertainties to potentially exploit "common mode" features between weighting functions by utilizing O_2-derived P_{sfc} in retrievals
  - Eliminates the dependency on modeled P_{sfc}, but still dependencies on T/RH that impact retrieval accuracy
  - Near surface and regions highly sensitive to T and RH benefit from combined CO_2/O_2 and CH_4/O_2 retrievals